THE PETROVALVE PLUS :
AN INNOVATION IN SUCKER ROD PUMP VALVE TECHNOLOGY

by
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Abstract:

The Petrovalve technology eliminates the high failure rate and low efficiency inherent to the traditional ball and seat valve configuration which has been in use for the last 70 years. These improvements are due to the guided seating surfaces of the Petrovalve design, providing some exciting opportunities for producing oil companies through both material selection and operating variables. With a larger flow area and less pressure drop across the valve, the Petrovalve design allows for increased pump efficiency. Production increases of 35% are not uncommon in the field.

Eliminating gas lock problems common to many thermal and non-thermal well pumping operations is the Petrovalve Gas Breaker. The traveling valve automatically opens at the end of each cycle allowing the hydrostatic fluid to flow through and exchange any trapped gas accumulations. Available in cast cobalt alloy (stellite), tungsten carbide, and titanium carbide, the whole line of Petrovalve products offers increased production and decreased maintenance costs and downtime. Through greater pump efficiency and the versatility to operate at deviated angles, right through to the horizontal, oil producers see a direct effect on the bottom line.

Executive Summary

The basic design of the Petrovalve differs from that of the conventional ball and seat configuration in that the ball has been replaced by a guided ball and shaft to allow for only one degree of freedom in the ball's motion.

The ball and shaft, or plunger, of the Petrovalve system consists of a hemisphere with a relatively narrow diameter and a shaft fixed through the centre of the hemisphere. This plunger travels inside the limits of the guide ribs of the cage, or insert, without restricting the flow of fluid past the open valve. The shaft forming the top and bottom stems of the plunger centralizes and guides the movement of the plunger. The stems are guided longitudinally by loose fitting apertures in the webs of both the cage and seat, providing perfect alignment of the valve seating surfaces.

With only three ribs forming the cage, there is a subsequent widening of the cage windows and an increase in cross-sectional flow area. This allows for less restricted flow, and thus, increased flowrates and less pressure drop across the valve. Since the stems are straight-sided and the web openings are circular, fluid may flush out accumulations of solids packing between the stems and webs.

With its superior flow efficiency, materials selection and service life, the Petrovalve offers a proven alternative to the conventional ball and seat valve configuration.

1. Background:

1.1 The History of the Ball and Seat Valve in the Bottom Hole Sucker Rod Pump:

Since the early 1920s, the oil industry has primarily used the sucker rod pump for the extraction of oil to the surface. Over the last 70 years, there has been little change in the design of the valves used in this type of pump. Even with its short service life, poor fluid dynamics and serious limitations in harsh pumping environments, the ball and seat has thus remained the only bottom hole pump valve choice for oil producing companies. Over the years, only the configuration and materials have changed while the basic concepts have stayed the same.

The sucker rod pump, basically a reciprocating pump, consists of a plunger housed by a barrel. Each pump has two check valves; one is located at the end of the plunger and the other is located at the bottom of the barrel. The former is referred to as the traveling valve and the latter is referred to as the standing valve. On the up-stroke, the traveling valve closes and creates a suction on the fluid below. Well bore fluids, being primarily incompressible, begin to flow into the bottom of the pump through the now open standing valve. On the down-stroke, the standing valve closes and the trapped fluid enters the plunger through the now open traveling valve, thus completing one pumping cycle.

The problem with this valve configuration is, on the opening cycle, the ball lifts and rattles around widely as the fluid passes through the valve. The closing cycle is then slowed down since the ball experiences difficulty locating its seating position. This random movement of the ball constantly acts against fluid flow as it constantly searches for a path around the ball. This haphazard behaviour of the valve induces erratic flow patterns and backflow around the moving ball. This induced turbulence reduces the pumping efficiency and generates an accumulation of sand and other particles in the valve.

In addition, due to the vibrational nature of the ball's motion and the cyclical operation of the pump, the repeated impact of the ball against the seat and housing lining leads to the premature and unpreventable destruction of the valve. In common pumping situations, the ball will strike the cage lining about 280,000 times per day causing stress chipping and scratching of the most crucial surfaces of the rod pump. The ball itself is manufactured with a highly polished surface and must pass a vacuum sealing test prior to being considered suitable for use in a well. Once this surface is damaged, the effective sealing of the ball and seat system is destroyed. In severe pumping conditions -- such as heavy oil with high abrasive sand content, the presence of H_2S, CO_2, gas pockets and high temperatures -- the corrosion, abrasion and damage are accelerated dramatically.

It can be said that the design of the ball and seat system is fundamentally flawed. If a well is flowing with clean, non-corrosive fluid, the valve will destroy its sealing surfaces and housing by virtue of its design alone. In 1951, an "insert" was introduced to restrict the violent, self-destructive movement of the ball. Inserted from the top end of the valve housing, it seats on the inner shoulder and locks into place with an annular seal ring and the top sub (plunger connector or barrel connector). The sidewall of the insert typically has four windows separated by the longitudinal members which are referred to as guide ribs. At its upper end, the insert has a transverse stop bar which limits the upward motion of the ball. The ball fits loosely in the insert so that it can easily leave the seat and move up or down within the insert. However, its fit relative to the insert is close enough so that the ribs effectively guide it and prevent it from rattling around excessively from side to side within the insert. This solution was only partially successful in slowing wear. The damage was not eliminated. In addition, the physical dimensions of the insert have the effect of reducing flow area, and thus oil production.

This restriction through the valve causes the majority of low efficiencies in sucker rod pumps. An example of this design is full flow valves, or as some call them, California style systems. These high output pumps are assembled with a small ball sitting deep in a large bore seat with an open design cage around it. This modified design successfully enlarges the effective flow area of the valve and gives you higher overall efficiencies, but retains the characteristic self-destructive behavior. This has manifested itself in a high damage or failure rate. Understanding the deficiencies of the ball and seat design helps to understand the material limitations for these systems.

The basic materials for balls and seats are cast stainless steel, cast cobalt alloys and a range of carbides. The combination of these metals mixed and matched with a host of other materials have always tried to overcome design flaws with hard wear resistant materials. There is, however, a limitation in the variety of materials available in the larger sizes of ball and seat valves. Larger balls are limited to stainless steel due to the weight of carbide and the brittle quality of the carbide and cast cobalt alloys. As the valve systems get bigger and the balls increase in weight from 1 lb to 20 lbs the damage is uncontainable. An example is the 3-3/4" pump. In 80 percent of applications, stainless steel ball and seat will be used even though carbide is harder and more wear resistant.

With the industry moving to deviated and horizontal completions, rod pumps are being asked to pump at high angles -- even in horizontal positions. Pumps equipped with open or full flow designs are commonly known to be very low producers on high angled wells or horizontal applications. Insert guided valve systems have been the preferred valve for such applications. The drawback to this application is again a loss of flow area due to the increased control over the ball.

1.2 The Incentive for Changing:

Faced with the high failure rate, low efficiency, and material limitations of the conventional API bottom hole pump valve system, Mr. Doug Jensen and Mr. Ken McConnel of Edmonton, Alberta, created a replacement for the API ball and seat valve. The guided alignment system of the Petrovalve Plus was aimed at increasing production potential, service life and availability of valves in the hardest most wear resistant materials on the market, without being limited by size. With their combined 42 years of experience in the operation and servicing of sucker rod pump equipment in the Alberta oilpatch, the two innovators spent years performing research and tests before arriving at the Petrovalve Plus system, a dramatic improvement on the ball and seat configuration (see figure 1). A Joint Research Venture with the Alberta Research Council proved successful in the development of the valve system materials.

In order to fully realize the potential improvements that could be made with a better valve system than the ball and seat, one must think in terms of a single stroking cycle of the sucker rod pump. There are only a handful of variables involved in this process of pump fillage. The filling of the pump cavity on the up-stroke has a set time which is dependent on the speed of the pumping unit. This relates directly to the speed of the plunger. The variables affecting, or limiting, the full pump fillage are as follows:

1. The integrity of the barrel and plunger to create maximum vacuum on the up stroke.
2. The I.D. of the opening to the barrel or flow area through the standing valve.
3. The viscosity of the oil entering the pump.
4. The fluid dynamics of the standing valve configuration or the smoothness of flow through the entry point of the pump.

Consider a system pumping at six strokes per minute. At this speed, the pump must fill within five seconds. This is to say that a complete cycle is 10 seconds in duration and half of that time, five seconds, is suction on the up-stroke. The pump efficiency is directly affected by the ability of the valve to allow maximum flow area, and by the time required for the ball to find its seat after rattling about uncontrollably.

The latter five seconds of the pumping cycle is the exchange of fluid from the barrel cavity through the I.D. of the traveling valve and plunger I.D. on the down-stroke. This exchange of fluid has the same limiting factors as the entry point of the pump, however, they manifest themselves differently in the traveling position. Specifically, the effects are often slow rod drop, and rod breakage due to the differential loading between the surface unit and the pump. In addition, since the traveling valve is most often a smaller size than the standing valve, the physical ability of the traveling valve to exchange fluid.

These limitations are controllable. By improving the valve design, the overall pump efficiency can be improved. By improving valve closing time, flow area, and control of the valve components, the possible gains in production are substantial. Add to this reductions in service requirements and increased service life. The developers of the valve recognized this and responded with the Petrovalve Plus guided valve system.

2. The Petrovalve Design:

The Petrovalve Plus system was designed to exhibit improved flow area and control of the sealing surfaces and to eliminate the self-destructive nature of the ball and seat configuration. The valve assembly, consisting of three separate components (the plunger, the seat, and the insert), operates with only a single degree of freedom in its movement -- longitudinal. Each component is designed to minimize flow disturbance and restriction. A comparison of the traditional ball and seat configuration with the Petrovalve Plus system is shown in Figure 1.

The plunger is the key innovation of the Petrovalve system, although it retains the same function as the ball of the ball and seat system. The Petrovalve plunger is basically a hemisphere (referred to hereafter as the ball) pierced along its centreline by a shaft. The shaft, extending longitudinally from both sides of the ball, provides the required control, guiding it in a straight line through its complete range of motion. When open, the ball remains centred in the valve housing, allowing for an equal distribution of flow. When closed, the ball falls directly onto the seating surface for an immediate seal.

The plunger is guided by two apertures; one is located in the seat below the ball while the other is located near the top of the insert. These guides ensure that a consistent path of travel is maintained and that the ball lands precisely at the centre of the seat at the end of each cycle. In addition, nicking of the valve seal surface is avoided due to the lack of any rattling against the insert ribs.

The two components of the plunger, the ball and the shaft, possess different material requirements due to their different functions in the operation of the valve. The primary requirement of the ball is that it be both wear resistant and corrosion resistant. The shaft, however, must possess great strength and toughness. It was found to be more feasible to manufacture the plunger in the two separate components. This permits the selection of different materials and manufacturing processes for the ball and the shaft. Thus, the different requirements of each component are met more easily.

The Petrovalve seat differs, as mentioned above, from the seat of the traditional valve configuration by possessing a guide at the bottom of the seat. This guide does not affect the flow area, as the inner diameter of the seat has been increased on the entry portion of the seat. For the same size of valve, the Petrovalve seat has roughly a 10% larger entry I.D. and a smaller thickness, providing the equivalent or more cross sectional flow area than the API seat.

The valve insert design is a compromise between fluid flow requirements and structural strength. First, the insert must guide the plunger onto the seating area of the seat. Second, the insert must provide as much flow area as possible. These requirements would, of course, be met best by an insert with the fewest and thinnest guide ribs possible. However, it must also be strong enough to sustain cyclical loading. In addition, the insert material must resist corrosion and erosion from the abrasive particles. The design of the Petrovalve insert satisfies all of the above criteria.

The insert has a connector or bottom ring, three longitudinal, equally spaced ribs (valves larger than 2-1/2 inches have inserts with only two of such ribs) and a web connected to the ribs at the top. A central aperture is found in the web to guide the top plunger stem. When the Petrovalve insert is compared to that of the conventional ball and seat valve, it is clear that the space taken up by the insert ribs is reduced and the windows are widened.

3. A Discussion of the Benefits of the Petrovalve:

With numerous opportunities to improve on the performance of the traditional ball and seat valve configuration, the Petrovalve exhibits many different strengths. Stemming from the guided alignment system, the design principles lead to such improved performance factors as a larger flow area, more streamlined flow, less pressure drop, longer service life, and greater versatility.

All of the design changes discussed above, such as the smaller diameter of the hemispherical ball, the larger bore diameter of the seat and the widened windows of the insert have served to increase the flow area of the valve. Depending on the valve size considered, mathematical calculations indicate that the cross sectional area of the Petrovalve is 27% to 112% larger than that of the API valve. Figures 3 and 4 are sample flow area calculations of the 3-3/4" ball and seat valve and the Petrovalve. Please note in these figures that Area '2', being the minimum flow area in the valves, is the basis of comparison.

One indicator of flow efficiency through a valve is pressure drop. An evaluation, performed by the Alberta Research Council (ARC) and the Alberta Oil Sand Technology and Research Authority (AOSTRA) in 1991, of relevant characteristics of sucker-rod pump valves, suggested the use of measured static head loss for assessing the flow efficiency of the valve. Empirical data indicated that the Petrovalve is one of the best among 19 different brands of valves tested, according to certain AOSTRA criteria. A great number of tests in the oil field have confirmed these results.

Another indicator is, of course, production. Operating field data are impressive. Without changing any other working conditions and replacing the API valve with the Petrovalve, oil production can be increased by more than 30% and, in some cases, even by up to 160%.

Under the Petrovalve International Inc. / ARC Joint Research Venture (JRV), new materials and processing technologies have been tested and evaluated for the effects of corrosion, abrasion, wear, high temperature and many other conditions in operating oil wells. The research also considered material strength and toughness, as well as adhesives for valve components. Significant achievements have been made in applying the results of these research efforts to Petrovalve products. As observed from the test data received from the Canadian, American and Venezuelan sites, the Petrovalve system lasts 30% to 50% longer than the API style valve. These positive results show that the work completed during the selection of materials and manufacturing technologies was indeed very effective.

Past field experience in both thermal and non-thermal well pumping operations has indicated that reduced pumping efficiency due to gas and vapour flashing is a major problem. In more severe situations, the gas lock can actually lead to the interruption of well production. In a gas lock situation, steam and non-condensable gas build up between the traveling valve and the standing valve. The pressure of this gas holds the standing valve closed while the hydrostatic weight of the fluid above the pump prevents the traveling valve from opening. As the pump plunger descends, the trapped gas is compressed, but little or no fluid is actually exchanged. As a result, the producing oil company experiences more downtime, higher maintenance costs, and lower profits when using the traditional ball and seat valves in this situation.

To combat this problem, the Petrovalve Gas Breaker was developed. As an extension of the Petrovalve technology, the Petrovalve Gas Breaker (used only in the traveling valve position) automatically opens at the end of each cycle allowing the hydrostatic fluid to flow through and exchange any trapped gas accumulation between the two valves, thus allowing new oil to enter the pump. As shown in Figure 2, this automatic opening is accomplished with an extended bottom stem and a trip sub.

The Petrovalve Gas Breaker also proves its worth in gas fields which carry fluids. This valve can be used to control the height of the water column in the well to prevent the equalization of the formation pressure which stops gas production.

Designed for use as the traveling valve in thermal and non-thermal well pumping situations, the Petrovalve Gas Breaker can be used with existing conventional type valves. However, when combined with the Petrovalve Plus in the standing valve position, production efficiency is maximized while maintenance costs and replacement costs are minimized.

Experience accumulated during the last 20 years with extra-heavy oil production and bitumen in Western Canada indicates that pump seizure due to the accumulation of sand has been a severe problem specific to unconsolidated reservoirs. The ARC, through research and investigation into this problem, has determined that the valve (API Ball and Seat configuration) is the first place for sand accumulation to occur due to the flow turbulence caused by the rattling movement of the ball.

By limiting flow turbulence, the Petrovalve design maintains laminar flow in most cases, This allows for continuous flushing of the valve to prevent sand accumulation. As Juch and Watson have found, by streamlining the flow there is a reduction in sand and particle accumulation. In addition, the loose fit of the plunger and the provision of the openings for easy flushing are also helpful in preventing seizure caused by sand. Thus, the sand abrasion and wear to the seat and plunger is reduced, consequently extending the life of the valve.

Petrovalve Plus' patented design has also had a positive effect on deviated wells that present problems such as premature valve failure caused by uneven wear of valve surfaces. Many API systems, or ball and seat configurations, have attempted with little success to control the movement of the ball by tightening the tolerances surrounding it. The end result of this solution has always been a dramatic drop in the efficiency of the pump.

Tests were conducted on a large pump simulator with the ability to lay a rod pump on its side while pumping. The efficiency of the conventional valve systems was shown to drop as the angle from vertical of the simulator increased. Efficiency levels at angles greater than 35° were extremely low. In contrast, Petrovalve Plus pump valves are not affected by this change in orientation of the pump. Petrovalve's guided system performs just as effectively on the deviated angle, even when horizontal, as in the vertical position. This is because the guide system keeps seating surface aligned at all times, allowing for less valve failure and greater operating efficiency.

In most horizontal wells the rod pump systems are landed at or near the vertical position in the well bore because of the reduced efficiency and high failure rate if placed in the horizontal position. The hydrostatic weight of the fluid in the well bore from vertical to horizontal position restricts the pay zones ability to produce fluid. The reservoir pressure must push the fluid up the production string to the pump's landed depth before it can be brought to the surface. This results in reduced production volumes. Petrovalve Plus is designed to allow for high efficiency pumping in any position, resulting in service cost savings and increased production.

4. Summary

The advancement of sucker rod pump valves has not occurred until recently with the Petrovalve. This advancement provides a number of benefits to the oil producing company through increased revenues and reduced operating and service costs. A larger flow area, greater availability of wear resistant materials in large valve sizes, greater flow dynamics, reduction of sand accumulation, and the ability to operate at any deviated angle all result in the ability to produce greater amounts of fluid.

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Juch, A.H. and Watson, R.J., "New concepts in Sucker-Rod Pump Design", JPT, pp. 49-61, 1969

Toma, P., Korpany, G., Sudol, T., and Gonie, K., "Hydrodynamic Characteristics and Comparative Study of Sucker-Rod Pump Valves", 1990/91 AOSTRA/Industry Thermal Well Pumping Committee, The Alberta Research Council, pp. 8, 1991

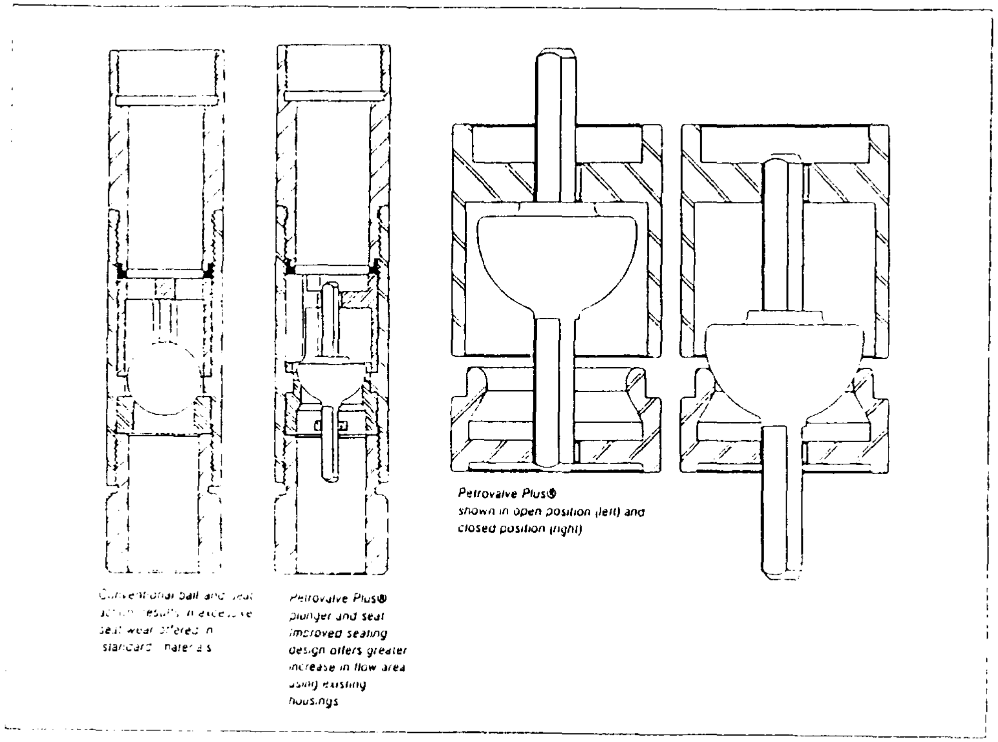


Figure 1 - Comparison of the Ball and Seat Configuration with the Petrovalve Plus System

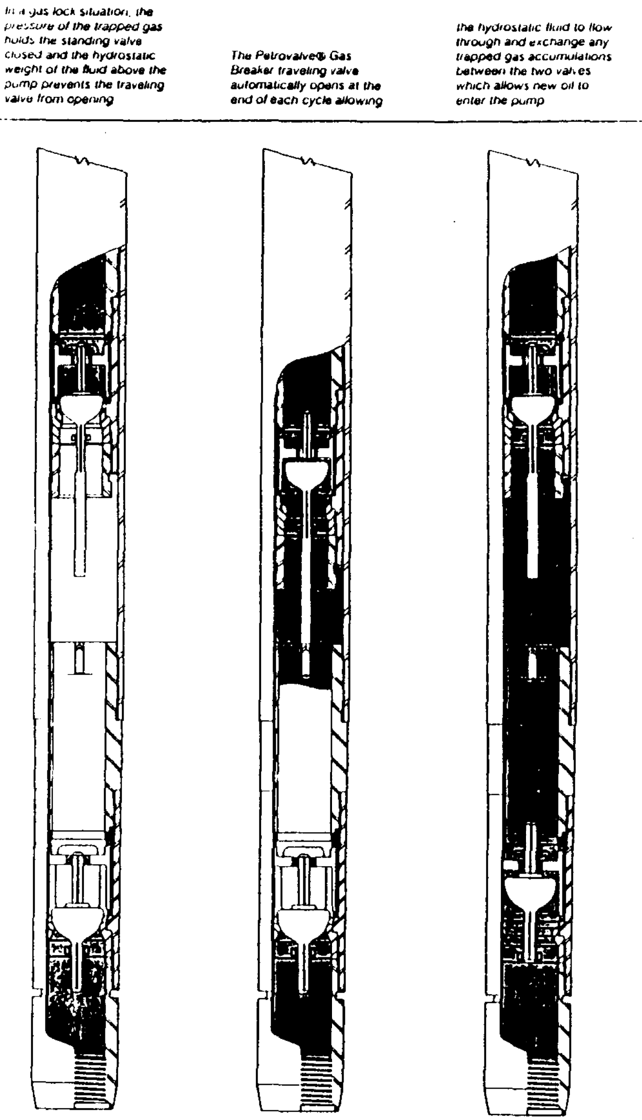
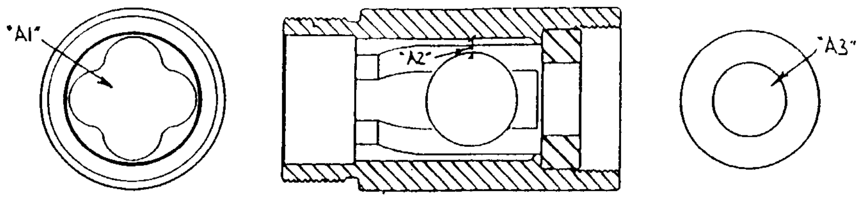


Figure 2 - Automatic Tripping of the Petrovalve Gas Breaker



AREA "A1"

a) $A1 = D^2 \times .7854 + [4 \times (\pi \times R^2 \div 2)]$

$A1 = 1.750^2 \times .7854 + [4 \times (\pi \times .750^2 \div 2)]$

$A1 = 5.940$ SQ. IN.

AREA "A2"

a) $A2 = (D^2 - d^2) \times .7854 + (4 \times (1/2 \times [r \times l - c \times (r - h)])$

$A2 = (2.325^2 - 2.250^2) \times .7854 + (4 \times (1/2 \times [.750 \times 1.250 - .750 \times (.750 - .250)])$

$A2 = 1.394$ SQ. IN

AREA "A3"

a) $A3 = D^2 \times .7854$

$A3 = 1.750^2 \times .7854$

$A3 = 2.405$ SQ. IN.

NOTE:

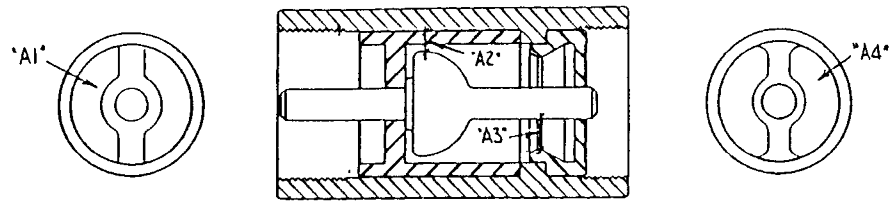
RADIUSES AND HOLES WERE NEGLECTED IN THESE CALCULATIONS.

RESTRICTION:

RESTRICTION IN THE VALVE IS BETWEEN HOUSING I.D. AND BALL O.D.

RESTRICTED AREA (A2) = 1.394 SQ. IN.

Figure 3 - Sample Flow Area Calculation of the 3-3/4" A.P.I. Style Ball and Seat Valve



AREA "A1"

a) $A1 = (D^2 - d^2) \times .7854 - [3 \times (\text{WEB WIDTH} \times \text{WEB LENGTH})]$

$A1 = (2.500^2 - 1.060^2) \times .7854 - [2 \times (.620 \times .720)$

$A1 = 3.133$ SQ. IN.

AREA "A2"

a) $A2 = (D^2 - d^2) \times .7854 - [3 \times (\text{WEB WIDTH} \times \text{WEB LENGTH})]$

$A2 = (3.073^2 - 2.280^2) \times .7854 - [2 \times (.282 \times .620)]$

$A2 = 2.984$ SQ. IN

AREA "A3"

a) $A3 = (D^2 - d^2) \times .7854$

$A3 = (2.015^2 - .547^2) \times .7854$

$A3 = 2.954$ SQ. IN.

AREA "A4"

a) $A4 = (D^2 - d^2) \times .7854 - [3 \times (\text{WEB WIDTH} \times \text{WEB LENGTH})]$

$A4 = (2.400^2 - 1.060^2) \times .7854 - [2 \times (.500 \times .670)]$

$A4 = 2.971$ SQ. IN.

NOTE:

RADIUSES AND HOLES WERE NEGLECTED IN THESE CALCULATIONS IN THE CAGE AND THE SEAT. (ASSUMED THAT THEY WOULD BALANCE EACH OTHER OUT).

RESTRICTION:

RESTRICTION IN THE VALVE IS BETWEEN SEAT I.D. AND PLUNGER STEM.

RESTRICTED AREA (A3) = 2.954 SQ. IN.

Figure 4 - Sample Flow Area Calculation of the 3-3/4" Petrovalve Plus